HAMILTON HARBOUR
BACTERIA SURVEY 1990

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HAMILTON HARBOUR BACTERIA SURVEY 1990

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ABSTRACT

In response to recommendations arising from the Hamilton Harbour Remedial Action Plan (RAP) process, a preliminary bacteriological survey was undertaken by the Great Lakes Section of the Ontario Ministry of the Environment's (MOE) Water Resources Branch. The objective of the investigation was to ascertain whether conditions at one or more potential beach sites showed sufficient promise to justify more intensive feasibility studies examining the influence of specific sources and the need to improve access. The study incorporated sampling on 15 days spanning July, August, and September at 12 stations distributed over three potential swimming areas within the harbour. Samples were collected so as to emulate the procedures currently employed by municipal Health Units at existing beaches outside the harbour and were analysed by the Ministry of Health laboratory in Hamilton which services the current beach monitoring program. Results indicated that storm water runoff appeared to be principally responsible for large increases in densities of faecal coliforms and *Pseudomonas aeruginosa*, water quality tests such as temperature, conductivity, and water clarity were not useful indicators of bacterial densities and could not be used to attribute sources, and the harbour stations evaluated fell in the middle of the range exhibited by existing beach stations outside the harbour in terms of both geometric mean densities, and the frequency of observations above the MOE objective of 100 organisms 100 ml^{-1}. As a consequence, the principal conclusion from the study was that there is potential for swimming at all three zones examined and that further, detailed investigation is indeed warranted.

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INTRODUCTION

Through the Remedial Action Plan (RAP) process, swimming at certain locations within Hamilton Harbour has been identified as a beneficial use which should be restored (Ontario Ministry of the Environment *et al.* 1989). Although swimming is currently prohibited and access is extremely limited, zones in the southwest end and along the north shore have been recommended as potential sites for future recreational swimming opportunities. Bacterial contamination affecting the potential for swimming in these areas appears to be predominant after rainfall (Ontario Ministry of the Environment *et al.* 1989) suggesting that storm sewers and CSOs discharging to the harbour and north shore tributaries may be the most immediate cause.

In response to this interest in establishing swimming in the harbour, the RAP Team agreed to investigate the suitability of several zones within the harbour under existing conditions. This investigation was intended to provide general baseline data to guide future decisions regarding the siting of public swimming areas (and any associated necessary remedial actions) prior to undertaking more intensive feasibility studies relating to the influence of specific sources and the need to improve access. In essence, this study was undertaken to ascertain whether conditions at one or more potential beach sites showed sufficient promise to justify further study or whether they were clearly unacceptable. This study was not intended to provide all data necessary to identify specific locations and their corresponding management strategy.

The 1990 survey was designed to measure the density (geometric mean) and variability of pathogenic and indicator bacteria at three potential (future) public swimming zones within the harbour. These data were intended to provide the basis for a cooperative decision among the Hamilton Harbour RAP Team and Stakeholders regarding the future actions necessary to restore swimming at one or more areas within the harbour.

A preliminary meeting was held with representatives from the Regional Municipalities of Hamilton-Wentworth and Halton, the Ministry of Health Regional Public Health laboratory, and the Hamilton Harbour RAP Team to identify: (a) the harbour zones to be examined, (b) the distribution of sampling locations among these zones, (c) the survey dates and sampling frequency, and (d) the sample analyses to be undertaken.

SURVEY DESCRIPTION AND METHODS

Sampling was undertaken by the Ontario Ministry of the Environment (MOE) at five locations in the vicinity of LaSalle Park, two in the vicinity of Willow Point, and five near the proposed waterfront park in the southwest corner of the harbour (see Figure 2.1). Two successive replicate samples were taken at each location on three days (no sampling on Fridays or weekends) during five sampling weeks over the period early July to early September.

All 24 samples generated each sampling day were analyzed for faecal coliforms and *Pseudomonas aeruginosa*. A subset of five samples per day was analyzed for *E. coli*. Secchi depths (a measure of water clarity), water temperature and conductivity (a measure of total dissolved solids) were recorded at each sampling point.

Samples were collected from the extreme near shore area in water depths of approximately 1.5 m by submerging the sterile sampling bottle to a depth of approximately 0.3 metres. This procedure was intended to duplicate the standard procedures of the municipal shore-based beach sampling protocols, although absolute consistency could not be guaranteed. Samples were preserved by refrigeration on ice in containers provided by the Regional Public Health laboratory in Hamilton.

All sample analyses were undertaken by the Regional Public Health laboratory according to their standard procedures.

RESULTS AND DISCUSSION

Faecal Coliform Results

Table 3.1 lists the results of analysis for faecal coliforms and shows the geometric means at each location for all samples. For computational purposes, values greater than 1200 and 2400 (prefixed with a "G") were assigned values of 1200 and 2400 with the realization that the resulting means would be underestimated and that the assumed log normal distribution would, therefore, be skewed. These errors were deemed acceptable for the purposes of the simple analysis presented below.

The summary also includes precipitation data obtained from the federal meteorological station at Hamilton airport (Environment Canada 1990). These data have been used to estimate antecedent precipitation which, for the purposes of this illustrative exercise, was defined to be the sum of total precipitation measured on the sampling day and the day preceding the survey. The intention here was to make some allowance for the lag time between rain events and effects in the harbour, while

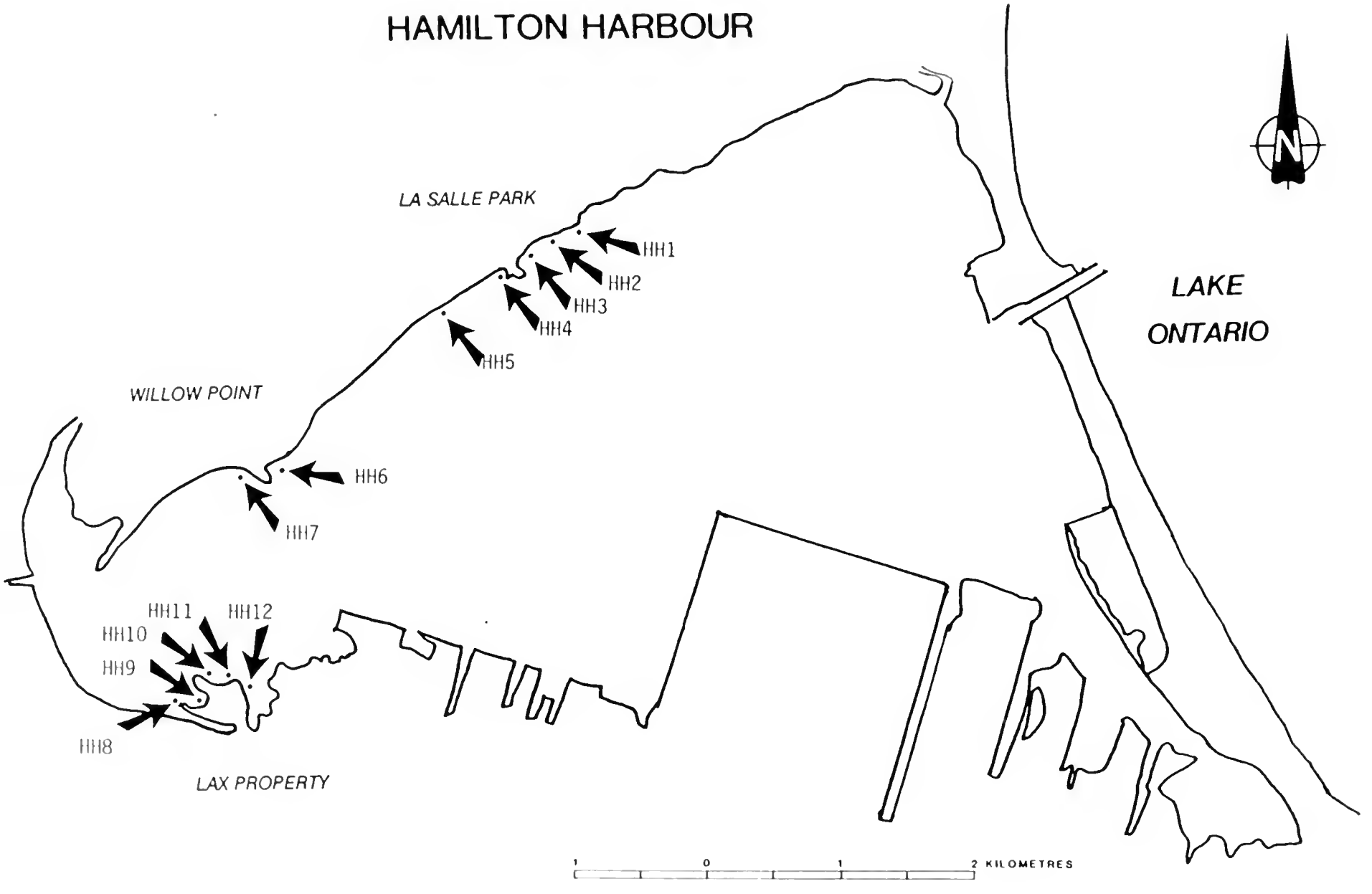

FIGURE 2.1 Hamilton Harbour 1990 Bacteria Survey Station Locations

TABLE 3.1 HAMILTON HARBOUR BACTERIA SURVEY 1990, FAECAL COLIFORMS (ORGANISMS/100 ML)

DATE	ANTE-CEDENT PRECIP. (MM)	LASALLE PARK					WILLOW POINT		LAX PROPERTY				
		HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8	HH9	HH10	HH11	HH12
10/07/90	0.1	72	112	88	148	108	124	136	264	302	324	212	268
		52	72	124	136	88	88	92	294	278	254	144	284
11/07/90	0.1	56	G 1200	84	126	118	146	780	166	190	94	246	278
		72	G 1200	62	148	166	178	840	162	174	64	132	304
12/07/90	0.6	108	144	172	246	264	326	194	132	216	226	234	346
		82	108	164	298	234	342	212	100	234	238	212	374

31/07/90	0.4	30	24	90	68	24	50	48	38	28	96	60	64
		32	26	64	46	48	38	18	36	46	64	54	68
01/08/90	0.0	132	46	160	164	80	120	22	72	70	70	90	106
		116	60	112	180	106	118	32	52	42	78	72	56
02/08/90	0.0	176	168	132	172	128	300	20	92	40	60	68	168
		260	128	84	176	220	280	44	128	36	72	100	160

13/08/90	25.6	G 1200	G 1200	G 1200	G 1200	128	136	78	484	G 1200	G 1200	324	164
		G 1200	G 1200	G 1200	G 1200	84	184	84	420	G 1200	G 1200	852	194
14/08/90	16.5	G 1200	92	128	G 1200	136	1000	126	G 1200	G 1200	G 1200	G 1200	G 1200
		G 1200	174	108	G 1200	120	1200	148	G 1200	G 1200	G 1200	G 1200	G 1200
15/08/90	0.0	136	68	412	620	206	294	G 1200	G 1200	G 1200	G 1200	G 1200	G 1200
		144	124	G 1200	652	242	264	G 1200	G 1200	G 1200	G 1200	G 1200	G 1200

27/08/90	41.4	120	28	68	88	60	112	16	180	216	148	120	184
		80	52	80	84	72	76	28	260	208	128	112	176
28/08/90	57.6	G 1200	24	100	G 1200	64	150	34	G 1200	G 1200	G 1200	160	92
		G 1200	34	104	G 1200	50	160	26	G 1200	G 1200	G 1200	104	140
29/08/90	16.2	280	84	152	720	296	80	124	G 2400	G 2400	G 2400	G 2400	720
		360	144	140	680	272	168	132	G 2400	G 2400	G 2400	1200	640

04/09/90	2.4	60	30	140	240	70	130	82	54	62	48	40	80
		80	18	140	200	70	100	50	66	74	40	36	50
05/09/90	2.5	36	40	64	42	400	70	40	70	40	46	48	44
		38	20	70	50	300	70	40	70	40	48	42	50
06/09/90	2.4	50	80	400	160	60	60	56	50	40	60	30	100
		50	54	G 1200	30	60	30	80	88	22	48	80	120
GEOMETRIC MEAN		146	89	158	236	115	144	84	221	211	221	175	198

recognizing that the small drainage areas associated with many of the potential sources (i.e. creeks and sewersheds) could be expected to respond within hours. Any follow-up quantification of rainfall effects would require the use of hourly precipitation data, preferably from the meteorological station at the Royal Botanical Gardens, and high frequency sampling in the harbour.

Only two of the twelve locations displayed seasonal geometric means less than the Provincial Water Quality Objective (PWQO) of 100 organisms 100 ml^{-1} for swimming and bathing use of water (Ontario Ministry of the Environment 1984): one near LaSalle Park, and one near Willow Point. These data should not be interpreted as indicating that these were the only acceptable locations for swimming, however, since results were highly variable within zones and between survey periods. All locations had some days with bacterial densities below the PWQO.

A 2-way analysis of variance (ANOVA) on the log transformed data (Appendix A) shows that:

(a) there were significant differences in geometric means among the five stations at LaSalle Park as well as among the two stations at Willow Point,

(b) there were highly significant differences among survey weeks at all locations, and

(c) significant interaction between sampling locations and survey weeks occurred at all three zones.

The interaction between stations and surveys is important since it indicates that relative differences among stations were not consistent from one survey period to the next. This means that it is not possible to generalize about spatial patterns on the basis of one survey period, nor is it appropriate to speculate about temporal trends by examining any single location.

Despite these interpretational constraints it is clear that the variability from one week to another was greater than the variability from one station to another. It is also clear that the Lax Property zone differed from the others in that no significant differences are evident among the five stations sampled.

Comparison of the day-to-day fluctuations with the pattern of antecedent precipitation strongly suggests that storm water runoff was principally responsible for massive increases in densities of faecal coliforms, particularly in the vicinity of the Lax property. Future investigations should focus on storm water discharges since these are the most probable cause of the extremely high temporal variability observable in the data.

Comparison of that subset of harbour data corresponding to those selected municipal data obtained on the same sampling days (Table 3.2) at the nearby Lake Ontario bathing beach locations shows the harbour geometric mean densities are not significantly different from those at existing bathing beaches.

TABLE 3.2: COMPARISON OF MOE AND HEALTH UNIT BACTERIA RESULTS 1990

STATION LOCATION	NO.	+95% C.I.	GEOM. MEAN	-95% C.I.	N	% OF SAMPLES > 100	% OF SAMPLES > 300
(MOE STATIONS)							
LASALLE PARK	HH 1	317	190	114	24	75	29
LASALLE PARK	HH 2	189	113	68	24	50	17
LASALLE PARK	HH 3	219	152	105	24	63	17
LASALLE PARK	HH 4	471	302	194	24	83	42
LASALLE PARK	HH 5	151	115	88	24	63	0
WILLOW POINT	HH 6	240	172	123	24	79	17
WILLOW POINT	HH 7	162	94	54	24	46	17
LAX PROPERTY	HH 8	515	300	174	24	75	42
LAX PROPERTY	HH 9	573	314	172	24	75	46
LAX PROPERTY	HH10	564	324	186	24	67	46
LAX PROPERTY	HH11	400	247	152	24	75	33
LAX PROPERTY	HH12	382	258	174	24	83	38
(MUNICIPAL STATIONS)							
CANAL	1	172	77	35	12	58	8
KILLARNEY	2	134	65	32	12	42	8
BEACH HOUSE	3	364	135	50	12	67	25
MARINE DOCK	4	319	106	35	12	58	33
CONFEDERATION PK. W	5	343	139	57	12	58	33
CONFED. PK. CHANGE	6	622	235	89	12	67	42
CONFEDERATION PK. E	7	803	321	128	12	75	58
GRAYS ROAD	8	628	204	66	12	50	42
GREEN ROAD	9	457	172	65	12	58	33
CHERRY BEACH	10	1144	539	254	12	92	67
FRUITLAND ROAD	11	383	140	51	12	50	42
MCNEILLY ROAD	12	361	111	34	12	50	25
WINONA ROAD	13	1741	560	180	12	83	75
FIFTY ROAD	14	496	155	49	12	58	33
FIFTY POINT	15	229	97	41	12	50	17

Means and confidence intervals expressed in organisms/100 ml

Coincident data available on: July 10, 11, 12, 31 and
August 1, 2, 13, 14, 15, 27. 28, 29

The frequency of beach closures at potential harbour locations relative to existing beach locations can be estimated by comparing their relative frequencies of densities greater than some arbitrary criterion. Sample frequencies in excess of 100 organisms 100 ml^{-1} (the PWQO) and 300 organisms 100 ml^{-1} (approximately half an order of magnitude above the objective) have been listed in Table 3.2.

Although this comparison of municipal and MOE data may not adequately accommodate differences in sampling methodology, the relative frequency of potential beach closures appears to be similar at both the MOE and municipal locations. At the low end of the spectrum, there were five municipal stations and only two MOE stations with at least 50% of their samples less than 100 organisms 100 ml^{-1}. On the other hand, there were three municipal stations with more than 50% of their samples above 300 organisms 100 ml^{-1}; a situation which did not occur at any MOE stations.

E. coli Results

The *E. coli* results (Table 3.3) were obtained as a more specific indicator of faecal contamination (an MOE study assessing the advantages of applying an *E. coli* objective is currently in progress). Comparison of the overall geometric means for the two stations where all samples were analyzed for both *E. coli* and faecal coliforms shows *E. coli* constituting 34% and 42% of the faecal coliform count which suggests that the application of an *E. coli* objective may be appropriate as a more direct indicator of a health risk associated with faecal contamination. As with faecal coliforms, a direct association between rainfall and *E. coli* densities is evident.

***Pseudomonas aeruginosa* Results**

Pseudomonas aeruginosa is a pathogenic organism which can provide better information concerning the risk of eye, ear, nose, throat and skin infections than faecal coliform data alone (Ontario Ministry of the Environment 1979). Survey results (Table 3.4) demonstrate negligible counts on 7 of the 15 sampling days and do not provide any cause for concern. On the other occasions, however, counts were high enough in the vicinity of Lasalle Park and the Lax property to indicate a potential health risk. Again, the precipitation data suggest that this was primarily the result of flows from storm sewers and combined sewer overflows (although the detection of this organism near the Lax property during the relatively dry first survey week may indicate a dry weather source requiring further investigation).

Physical Parameter Results

Examination of temperature and conductivity results (Tables 3.5 and 3.6) shows these to have varied very little. There were no significant differences among station means ($p < 0.01$) for either parameter which leads to the conclusion that variations in bacterial densities were not related to sources causing any corresponding variation in temperature or conductivity.

TABLE 3.3: HAMILTON HARBOUR BACTERIA SURVEY 1990, E. COLI (ORGANISMS/100 ML)

DATE	ANTE-CEDENT PRECIP. (MM)	LASALLE PARK					WILLOW POINT		LAX PROPERTY				
		HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8	HH9	HH10	HH11	HH12
10/07/90	0.1	34	72	80	--	--	--	--	--	--	--	--	--
		34	64	--	--	--	--	--	--	--	--	--	--
11/07/90	0.1	42	392	78	--	--	--	--	--	--	--	--	--
		72	442	--	--	--	--	--	--	--	--	--	--
12/07/90	0.6	56	142	168	--	--	--	--	--	--	--	--	--
		66	74	--	--	--	--	--	--	--	--	--	--

31/07/90	0.4	4	2	16	--	--	--	--	--	--	--	--	--
		L 2	16	--	--	--	--	--	--	--	--	--	--
01/08/90	0.0	32	30	36	--	--	--	--	--	--	--	--	--
		34	26	--	--	--	--	--	--	--	--	--	--
02/08/90	0.0	6	24	4	--	--	--	--	--	--	--	--	--
		12	32	--	--	--	--	--	--	--	--	--	--

13/08/90	25.6	G1200	G1200	G1200	--	--	--	--	--	--	--	--	--
		G1200	G1200	--	--	--	--	--	--	--	--	--	--
14/08/90	16.5	G 1200	74	108	--	--	--	--	--	--	--	--	--
		G 1200	68	--	--	--	--	--	--	--	--	--	--
15/08/90	0.0	70	16	48	--	--	--	--	--	--	--	--	--
		72	16	--	--	--	--	--	--	--	--	--	--

27/08/90	41.4	42	12	18	--	--	--	--	--	--	--	--	--
		10	14	--	--	--	--	--	--	--	--	--	--
28/08/90	57.6	G 1200	30	80	--	--	--	--	--	--	--	--	--
		G 1200	28	--	--	--	--	--	--	--	--	--	--
29/08/90	16.2	122	22	60	--	--	--	--	--	--	--	--	--
		84	36	--	--	--	--	--	--	--	--	--	--

04/09/90	2.4	16	10	40	--	--	--	--	--	--	--	--	--
		14	8	--	--	--	--	--	--	--	--	--	--
05/09/90	2.5	12	8	56	--	--	--	--	--	--	--	--	--
		6	10	--	--	--	--	--	--	--	--	--	--
06/09/90	2.4	8	32	84	--	--	--	--	--	--	--	--	--
		12	18	--	--	--	--	--	--	--	--	--	--
GEOMETRIC MEAN		50	37										

TABLE 3.4: HAMILTON HARBOUR BACTERIA SURVEY 1990, PSEUDOMONAS AERUGINOSA (ORGANISMS/100 ML)

DATE	ANTE-CEDENT PRECIP. (MM)	LASALLE PARK					WILLOW POINT		LAX PROPERTY				
		HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8	HH9	HH10	HH11	HH12
10/07/90	0.1	L 2	L 2	L 2	2	L 2	L 2	L 2	L 2	L 2	L 2	L 2	2
		L 2	2	L 2	L 2	L 2	L 2	L 2	2	L 2	2	L 2	L 2
11/07/90	0.1	10	L 2	12	L 2	L 2	12	10	4	10	6	8	4
		2	12	4	4	6	4	6	2	6	8	12	6
12/07/90	0.6	L 2	L 2	4	L 2	L 2	L 2	L 2	L 2	L 2	L 2	6	L 2
		L 2	4	L 2	L 2	L 2	L 2	2	L 2	L 2	L 2	4	L 2

31/07/90	0.4	L 2	2	L 2	L 2	L 2	L 2	L 2	L 2	L 2	L 2	6	4
		4	2	L 2	L 2	L 2	L 2	L 2	2	L 2	4	4	L 2
01/08/90	0.0	L 2	2	L 2	L 2	2	L 2	2	L 2	4	L 2	L 2	L 2
		4	L 2	L 2	L 2	L 2	L 2	L 2	4	2	2	L 2	L 2
02/08/90	0.0	2	L 2	L 2	L 2	6	L 2	L 2	L 2	L 2	L 2	L 2	L 2
		2	2	L 2	L 2	L 2	2	L 2	L 2	L 2	2	L 2	L 2

13/08/90	25.6	138	32	G 200	114	32	6	2	46	72	32	16	6
		52	2	14	112	4	6	2	24	82	58	24	22
14/08/90	16.5	60	L 2	8	100	L 2	L 2	L 2	40	30	48	24	20
		64	L 2	L 2	136	L 2	L 2	2	46	20	46	32	14
15/08/90	0.0	8	L 2	2	12	2	L 2	20	20	24	24	24	20
		20	L 2	4	8	2	4	24	28	18	44	30	24

27/08/90	41.4	2	L 2	L 2	L 2	L 2	L 2	L 2	L 2	2	L 2	L 2	L 2
		2	L 2	L 2	L 2	L 2	L 2	2	2	4	L 2	L 2	L 2
28/08/90	57.6	G 200	L 2	L 2	G 200	L 2	L 2	L 2	G 200	8	22	24	20
		G 200	L 2	L 2	G 200	L 2	L 2	2	G 200	20	20	12	44
29/08/90	16.2	18	L 2	L 2	24	4	L 2	L 2	104	66	64	32	12
		20	L 2	L 2	3	6	L 2	L 2	168	36	44	26	4

04/09/90	2.4	L 2	L 2	L 2	2	34	L 2	L 2	L 2	L 2	L 2	L 2	2
		L 2	L 2	L 2	L 2	16	4	L 2	L 2	2	L 2	L 2	2
05/09/90	2.5	0	0	0	0	0	1	0	1	0	0	1	5
		0	0	0	0	0	0	0	0	0	0	0	G 100
06/09/90	2.4	20	4	L 2	4	2	L 2	L 2	L 2	L 2	L 2	L 2	L 2
		L 2	L 2	L 2	2	L 2	L 2	2	L 2	L 2	L 2	2	L 2

TABLE 3.5: HAMILTON HARBOUR BACTERIA SURVEY 1990, TEMPERATURE (DEGREES CELSIUS)

DATE	ANTE-CEDENT PRECIP. (MM)	LASALLE PARK					WILLOW POINT		LAX PROPERTY				
		HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8	HH9	HH10	HH11	HH12
10/07/90	0.1	21.1	22.1	20.8	20.9	20.7	20.6	21.0	21.5	21.7	21.2	21.1	22.0
11/07/90	0.1	20.6	21.2	20.8	20.9	20.0	20.3	20.9	20.5	20.5	20.7	20.9	21.2
12/07/90	0.6	21.4	21.2	21.4	21.8	20.9	21.0	21.5	21.2	21.3	21.1	21.1	21.0

31/07/90	0.4	24.0	24.2	24.4	24.0	23.9	24.3	24.1	23.6	23.8	24.1	24.3	24.4
01/08/90	0.0	22.4	22.5	22.9	23.1	22.8	23.1	23.1	23.4	23.5	23.7	23.8	23.8
02/08/90	0.0	23.3	23.6	23.3	23.2	23.3	23.0	23.0	23.6	23.7	23.7	23.8	23.9

13/08/90	25.6	23.3	23.6	23.2	23.1	23.1	23.5	23.7	23.6	23.5	23.8	23.7	23.7
14/08/90	16.5	21.9	22.4	22.9	22.2	22.2	22.6	22.9	23.0	23.0	23.0	22.9	22.6
15/08/90	0.0	21.4	21.9	21.5	21.4	20.8	20.8	21.2	21.1	21.3	21.9	21.1	22.1

27/08/90	41.4	22.2	22.5	21.7	21.7	21.3	21.1	20.9	21.4	21.5	21.3	21.2	21.4
28/08/90	57.6	22.0	22.0	21.8	21.7	21.3	21.3	21.4	21.3	21.8	21.5	21.6	21.6
29/08/90	16.2	20.8	20.9	21.0	21.2	20.6	20.3	20.6	19.9	20.5	20.4	20.5	20.6

04/09/90	2.4	19.4	20.0	20.4	20.7	19.6	20.1	20.9	20.8	21.0	21.4	21.1	21.2
05/09/90	2.5	21.3	21.6	21.4	21.3	21.2	20.9	21.2	21.4	21.5	21.5	21.6	21.8
06/09/90	2.4	21.7	21.8	21.8	21.8	21.7	21.4	21.5	21.9	22.1	22.0	21.9	21.8
MEAN		21.8	22.1	22.0	21.9	21.6	21.6	21.9	21.9	22.0	22.1	22.0	22.2

TABLE 3.6: HAMILTON HARBOUR BACTERIA SURVEY 1990, CONDUCTIVITY (US/CM)

DATE	ANTE-CEDENT PRECIP. (MM)	LASALLE PARK					WILLOW POINT		LAX PROPERTY				
		HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8	HH9	HH10	HH11	HH12
10/07/90	0.1	602	606	605	604	607	602	602	601	601	599	601	604
11/07/90	0.1	609	606	610	613	611	608	607	604	602	601	607	606
12/07/90	0.6	611	614	621	622	614	615	611	611	610	611	612	609

31/07/90	0.4	583	578	568	582	582	577	577	580	573	579	577	577
01/08/90	0.0	573	588	577	581	576	571	578	582	579	581	580	581
02/08/90	0.0	587	571	574	583	591	577	582	585	581	582	582	581

13/08/90	25.6	580	536	552	556	566	550	560	566	567	564	564	563
14/08/90	16.5	576	540	556	532	563	558	564	573	572	570	570	568
15/08/90	0.0	579	530	566	562	564	566	563	568	568	563	565	565

27/08/90	41.4	527	517	534	531	530	530	531	537	537	534	536	537
28/08/90	57.6	513	519	520	515	528	527	532	533	535	533	535	534
29/08/90	16.2	540	532	531	531	530	533	530	536	532	533	535	534

04/09/90	2.4	528	502	511	522	527	525	523	528	527	523	526	523
05/09/90	2.5	518	507	515	516	515	514	521	529	522	524	523	523
06/09/90	2.4	520	501	513	519	529	520	522	529	527	524	524	523
MEAN		563	550	557	558	562	558	560	564	562	561	562	562

Water clarity measurements as indicated by Secchi depth measurements (Table 3.7), reflect a similar pattern to that of faecal coliforms with significant differences among stations ($F = 2.176$ for 11 d.f.), greater significant differences among survey weeks ($F = 15.46$ for 4 d.f.), and significant interaction between sampling locations and survey weeks ($F = 1.724$ for 44 d.f.). Although this method of estimating water clarity cannot be considered particularly accurate or precise (the differences among stations may not realistically reflect error associated with field measurement), the similarity in the pattern of variability between bacterial densities and Secchi depths could be interpreted as suggesting that turbidity is a reasonable indicator of bacterial densities. Such a finding would be consistent with the hypothesis that flows from sewers are the primary source of faecal bacteria in the harbour, but it could also be cited as evidence that resuspension and agitation of sediment contributed to increases in bacterial densities.

Correlating secchi depth measurements with faecal coliform densities (both raw data and log transformed data) from all 180 samples in order to substantiate this potential relationship between bacteria counts and water clarity reveals no meaningful correlation ($r^2 = 0.061$ for raw data, $r^2 = 0.052$ for log transformed data, with a negative correlation coefficient). Clearly, although water clarity and bacterial densities individually displayed a generally similar pattern of spatial and temporal variability, there was no correspondence on a sample-by-sample basis. Water clarity observations, therefore, cannot be considered a reliable indicator of bacterial counts, and are of relatively little value in attributing sources.

TABLE 3.7 HAMILTON HARBOUR BACTERIA SURVEY 1990, SECCHI DEPTH (M)

DATE	ANTE-CEDENT PRECIP. (MM)	LASALLE PARK					WILLOW POINT		LAX PROPERTY				
		HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8	HH9	HH10	HH11	HH12
10/07/90	0.1	G 1.0	G 1.0	0.8	1.0	1.0	0.9	0.9	0.6	0.6	0.6	0.7	0.8
11/07/90	0.1	G 1.0	1.0	0.8	1.0	1.0	1.0	1.0	0.7	0.8	0.7	0.6	0.8
12/07/90	0.6	1.1	0.8	1.0	1.0	0.8	0.5	1.0	1.0	1.0	1.0	0.8	0.5

31/07/90	0.4	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	1.5	1.0	1.7	1.5	G 1.0
01/08/90	0.0	G 1.0	G 1.0	G 1.0	1.5	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	1.5	G 1.0	G 1.0
02/08/90	0.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0	G 1.0

13/08/90	25.6	0.8	0.8	0.9	0.4	0.3	0.8	1.0	1.0	0.8	0.9	0.8	0.9
14/08/90	16.5	1.0	0.8	0.9	0.3	0.7	0.8	1.0	1.0	0.8	1.0	0.8	0.9
15/08/90	0.0	0.8	0.8	0.9	1.0	0.7	0.9	1.1	1.0	1.0	1.0	1.0	0.9

27/08/90	41.4	1.0	0.5	0.8	1.1	0.8	1.0	1.3	1.0	1.0	0.8	0.9	0.9
28/08/90	57.6	0.3	0.5	0.4	0.2	0.6	0.7	1.0	1.0	0.7	0.9	1.0	0.8
29/08/90	16.2	0.9	0.5	0.6	0.8	0.8	1.0	1.1	0.3	0.5	0.6	0.9	0.6

04/09/90	2.4	0.5	0.6	0.7	0.9	1.0	0.9	0.9	0.8	0.9	0.8	1.0	0.9
05/09/90	2.5	0.6	0.6	1.0	1.0	1.0	1.0	1.0	0.8	0.6	0.6	0.8	0.9
06/09/90	2.4	0.8	0.5	0.6	1.0	0.6	1.0	1.0	0.9	0.9	1.0	1.0	0.9

SUMMARY AND RECOMMENDATIONS

Summary of Results

Data collected during the summer of 1990 at potential swimming areas in Hamilton Harbour showed that:

(a) only two of the twelve locations sampled displayed seasonal geometric means less than the Provincial Water Quality Objective (PWQO) of 100 organisms 100 ml^{-1} for swimming and bathing use of water (Ontario Ministry of the Environment 1984): one near LaSalle Park, and one near Willow Point,

(b) there were significant differences ($p < 0.05$) in geometric means among survey weeks and among the stations near LaSalle Park as well as near Willow Point,

(c) relative differences among stations were not consistent from one survey period to the next (i.e. there was significant interaction between sampling location and survey period effects),

(d) storm water runoff appeared to be principally responsible for massive increases in densities of faecal coliforms and *Pseudomonas aeruginosa*, particularly in the vicinity of the Lax property,

(e) for the two stations where all samples were analyzed for both *E. coli* and faecal coliforms, *E. coli* constituted 34% and 42% of the total faecal coliform count,

(f) water quality parameters such as temperature, conductivity, and water clarity (measured concurrently with bacteria samples) were not useful indicators of bacterial densities and could not be used to attribute sources, and

(g) harbour stations fell in the middle of the range exhibited by existing beach stations; both in terms of mean bacterial densities and the frequency of observations above the MOE objective of 100 organisms 100 ml^{-1}.

These findings provide no evidence to preclude further efforts to establish bathing beaches within the harbour. Of the three zones examined, the Lax property was the least suitable having an overall geometric mean of 204 organisms 100 ml^{-1} with similar bacterial densities at all five stations. In contrast, the Willow Point zone was the best with an overall geometric mean of 110 organisms 100 ml^{-1}. Within this zone the western location (HH7) was the most favourable. Results from the Lasalle Park area, currently the most promising zone in terms of public access, fell between the other two zones with an overall geometric mean of 141 organisms 100 ml^{-1}. The second most easterly location (HH2) had the best results in this zone.

Recommendations

Whichever harbour zone, or zones, are considered for future development as public bathing beaches, successful management will depend largely upon the application of a policy regarding the reduction of

the health risks associated with swimming following rainfall. Ultimately, a follow-up investigation will need to be undertaken to focus on the specific relationship between rainfall and elevated bacterial densities at which ever locations are most likely to be designated as public beaches in terms of land use and accessibility. Such a study will allow the development of a post rainfall use policy and could proceed in conjunction with the necessary jurisdictional negotiations and agreements which will be required to restore this use of the harbour. This study may also provide additional incentive to remove completely the CSO discharges in the vicinity of the Lax property (if it is to be considered as a future bathing beach).

This study should incorporate the following specific components:

(a) a whole-season survey using the same sampling frequency and tests employed in the existing municipal monitoring programs (to verify the similarity between conditions in the harbour and conditions at current bathing beaches),

(b) high frequency sampling in the harbour and at storm sewers and combined sewer overflows during and following rainfall "events" for comparison with hourly precipitation data,

(c) investigation of possible dry weather flows from sewer discharges in the vicinity of the Lax property (if this location is to be seriously considered as a bathing beach), and

(d) analysis of a subset of samples generated by both the whole-season and wet weather surveys should be analyzed for *E. coli* and *Pseudomonas aeruginosa* as superior, direct indicators of faecal contamination.

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APPENDIX A: HAMILTON 1990 BACTERIA SURVEY 2-WAY ANOVA RESULTS

(ANALYSIS ON LOG TRANSFORMED FAECAL COLIFORM DATA)

CASE NUMBER 1: COMPARISON OF ALL 12 STATIONS

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
STATIONS	7.737	11	.703	6.889	2.300E-10
WEEKS	41.023	4	10.256	100.445	.000E+00
INTERACTION	19.111	44	.434	4.254	3.000E-14
ERROR	30.630	300	.102		
TOTAL	98.501	359			

CASE NUMBER 2: COMPARISON OF 5 LA SALLE PARK STATIONS

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
STATIONS	3.003	4	.751	6.046	1.760E-04
WEEKS	8.956	4	2.239	18.032	1.031E-11
INTERACTION	6.458	16	.404	3.250	1.037E-04
ERROR	15.521	125	.124		
TOTAL	33.937	149			

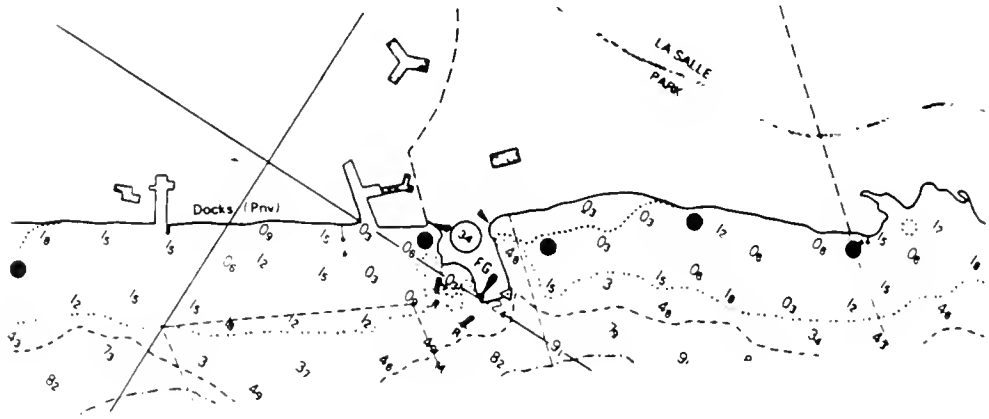
CASE NUMBER 3: COMPARISON OF 2 WILLOW POINT STATIONS

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
STATIONS	.802	1	.802	7.431	8.814E-03
WEEKS	5.347	4	1.337	12.378	4.526E-07
INTERACTION	1.092	4	.273	2.527	.0521
ERROR	5.399	50	.108		
TOTAL	12.640	59			

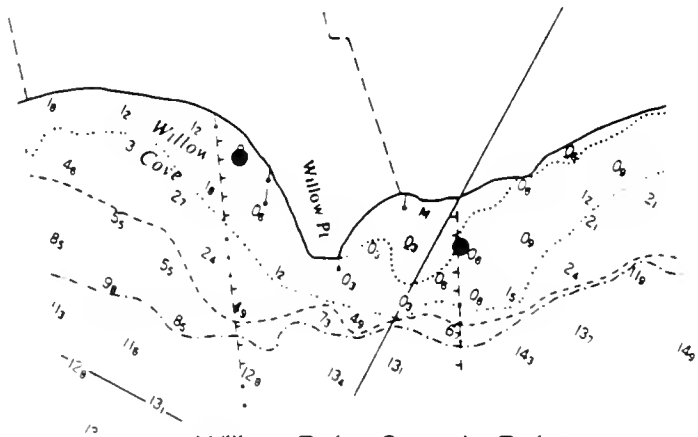
CASE NUMBER 4: COMPARISON OF 5 LAX PROPERTY STATIONS

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
STATIONS	.222	4	.056	.716	.5825
WEEKS	35.575	4	8.894	114.487	.000E+00
INTERACTION	2.707	16	.169	2.178	8.853E-03
ERROR	9.711	125	.078		
TOTAL	48.215	149			

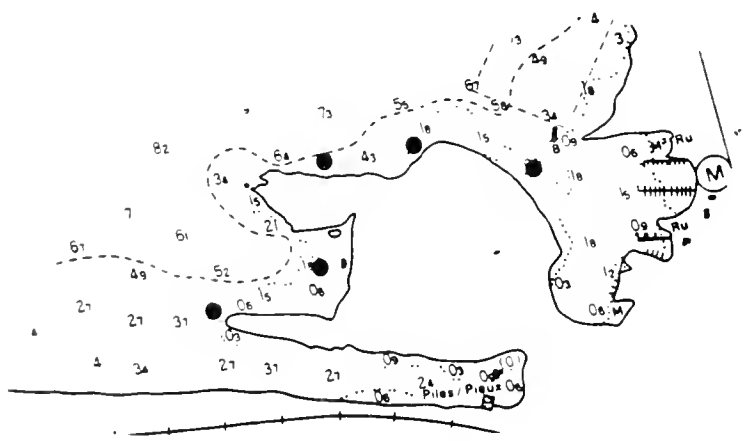
APPENDIX B: DETAILED STATION LOCATION MAPS



LaSalle Park Sample Points



Willow Point Sample Points



Lax Property Sample Points

Feet 1000 0 5000 Feets

Metres 1000 0 1000 Metres